research review

OAR: The Research Agency
of The United States Air Force

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AFOSR 10th ANNIVERSARY ISSUE

The Air Force Office of Scientific Research was officially established on 11 August 1955. It had existed, however, in recognizably similar form since 29 October 1951, with its roots going back still farther to the first appearance, in February 1948, of a basic research organization at Wright-Patterson Air Force Base.

That the Air Force entered the business of basic research when it did was due in great measure to the determination of the late Dr. Theodore von Karman, the distinguished, Hungarian-born aerodynamicist, who headed the Air Force's Scientific Advisory Board during the late 1940s. It was at Dr. von Karman's urging, and the urging of the entire Scientific Advisory Board that, in 1948, the Office of Air Research was established within the Air Materiel Command, the organization charged at that time with Air Force R&D. The Office of Air Research had a dual mission--performing research in its own laboratories, and conducting an extramural program by contract with industrial and university laboratories.

In April 1951, following the effective establishment of the Air Research and Development Command--the first Air Force command organization wholly devoted to research and development--the Office of Air Research was split in two. One portion remained at Wright Field, was designated the Flight Research Laboratory, and was given an applied-research mission. The other was attached to Headquarters ARDC, in Baltimore, Maryland, and given the job of running the contract program. It eventually became, in October 1951, the Office of Scientific Research (OSR). Colonel Oliver G. Haywood was appointed the organization's first chief.

OSR was mainly concerned with administering a research program which was largely basic rather than applied, and which was conducted entirely by means of contracts, mostly with university scientists. But, as a headquarters staff section, OSR also had a supervisory role with respect to other Air Force research activities. This role, however, existed more on paper than in practice, and was later eliminated.

OSR's research program was planned along the lines of the traditional scientific disciplines, and OSR itself was organized along

(Continued on P.4)

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From the Commander

In a departure from our normal publication practice, I am dedicating this issue of the OAR Research Review to the Air Force Office of Scientific Research (AFOSR) in celebration of its 10th anniversary. Although AFOSR is an integral part of the Office of Aerospace Research (OAR), its evolution was quite distinct. Let me explain.

As part of the general reorganization of Air Force research and development activities, OAR was formed on 1 April 1961 from what was then the Air Force Research Division, Air Research and Development Command (ARDC). ARDC became the Air Force Systems Command, and OAR became a separate operating agency with the procedural functions and responsibilities of a major air command.

OAR's constituent elements, however, had a longer history -- a history of providing new scientific knowledge and understanding. One such element, AFOSR, was established in August 1955. It was charged with administering an extramural basic research program. Since that time, there has been a steady growth in the size and scope of its research activities, particularly in those areas which offer the greatest potential for improving the present and future postures of the Air Force. To illustrate -- AFOSR (together with Convair) sponsored the First Astronautics Symposium which brought together over 600 scientists and engineers on problems involved in flight outside the atmosphere. This was in February 1957 - a time when space travel was still a feat belonging to the future.

Today, AFOSR is the major Air Force activity responsible for sponsoring extramural fundamental research in the sciences. It is supporting about 1,000 active research investigations with about 200 universities, industrial organizations and nonprofit research institutions in the U.S. and abroad. The quality of this research program can be recognized from the fact that AFOSR has supported a number of outstanding scientists, including Nobel Prize winners. In addition, a large number of university graduate students working on their advanced degrees under AFOSR contracts and grants have now become full-fledged senior scientists and principal investigators on their own, performing research not only for the Air Force, but also for the scientific community as a whole.

Thus, during the last decade, AFOSR has clearly demonstrated its capability to help OAR fulfill its over-all objectives, i.e., to increase scientific knowledge, and identify advanced concepts which will enable the Air Force to develop superior systems. I congratulate each member of the Air Force Office of Scientific Research on this occasion.

Don R. Ostrander

DON R. OSTRANDER
Major General, USAF
Commander, OAR

From the Executive Director, AFOSR

This special issue of the OAR Research Review highlights research supported by the Air Force Office of Scientific Research (AFOSR) in celebration of its 10th anniversary.

Over the years, AFOSR has been a heavy contributor to the Review. The articles contributed, including those in this issue, are solid tribute to the quality of research supported by AFOSR, as well as to the outstanding researchers whose work is described.

On this 10th anniversary, I wish to single out for special recognition the AFOSR project scientist -- the staff member who evaluates research proposals, makes the necessary decisions, effects the support, keeps up with developments in research, and attunes himself to Air Force research needs at the same time.

The research areas explored to satisfy these needs include nearly the entire scientific spectrum: general and nuclear physics, chemistry, mathematics, electronics, mechanics, energy conversion, astronomy-astrophysics, and the behavioral, biological and information sciences. Within these sciences, the project scientist is concerned with the evolution of specific disciplines, for example, thermodynamics, quantum mechanics, systems theory -- all building blocks for the technologies to which the Air Force is and likely will be committed.

Because of his competence in these areas, in which he has long years of research experience, the project scientist is called upon to recognize, in the proposal stage, basic research which holds the promise of application to existing technological problems in fields such as electronics, propulsion, and power generation. An added dimension to his job results from the fact that, in the main, our programs are not aimed at solving today's problems, but rather providing the know-how for as yet uncreated technology applicable to future operations.

To these ends, the project scientist must remain in tune with world-wide scientific developments as they occur, and be prepared to communicate ideas surrounding such new developments to the Air Force. Conversely, he provides the channel whereby Air Force needs are conveyed to science.

Thus, through his familiarity with the many current research efforts, as well as with Air Force needs, the AFOSR project scientist has been able, with notable success, to speed the results of research on to technological exploitation.

I take great pride in saluting the AFOSR project scientist. In a very significant way, he is strengthening today's Air Force and ensuring its superiority for tomorrow.

William J. Price

DR. WILLIAM J. PRICE
Executive Director, AFOSR

research review
OFFICE OF AEROSPACE RESEARCH

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JACOB SEIDEN
Editor

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these lines. There were originally five functional divisions--Chemistry, Fluid Mechanics, Mathematics, Physics, and the Solid State Sciences--each of which was headed by a division chief, usually a civilian, who was given considerable freedom in formulating a program for his division.

In February 1954, OSR's position in Headquarters ARDC was altered. At that time OSR was stripped of its staff supervisory functions and dropped down a step on the organizational ladder. The over-all supervision of ARDC research was now in the hands of a newly established Directorate of Research (Headquarters ARDC).

In August 1955, the Office of Scientific Research became the Air Force Office of Scientific Research (AFOSR), and was given "center status," meaning that it was henceforth to be regarded not as a headquarters staff section, but as an agency on the same footing with such ARDC field organizations as the Air Force Cambridge Research Center and the Wright Air Development Center. As a measure of the organization's new-found stature, a general officer, Brig. General Don B. Flickinger, was named its commander. The resemblance to a field organization was further sharpened in July 1956 when AFOSR severed its physical connection with Headquarters ARDC by moving from Baltimore to Washington, D.C.

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Officially, the granting of "center status" was designed to heighten the prestige and importance of research within the Air Force. Some AFOSR administrators felt, however, that it was really a step downward, since it placed the contractual research agency under--rather than within--command headquarters. During the following years AFOSR did, nevertheless, experience a steady growth in the size and scope of its research program.

Concurrently with the creation of AFOSR as a separate center, AFOSR was reorganized internally. This had little effect on the AFOSR program. The old divisions were either abolished and replaced by new directorates, or else directorates were superimposed upon the old divisions. The research programs continued as before, although in some cases under different men. The same general internal structure stands today.

AFOSR's new "center status" was accompanied by increased support. The organization's budget almost doubled from $13.9 million in fiscal year 1956 to $27 million in fiscal year 1959. The larger budgets permitted AFOSR to fund not only more projects but also more expensive ones, whose costs at one time had been prohibitive. Thus, the AFOSR program during the late 1950's possessed a variety, a quality, and a spark that it lacked in the earlier years.

In late 1959 and early 1960, ARDC underwent an extensive reorganization. This reorganization was designed to increase the effectiveness of ARDC operations by delegating certain management functions from Headquarters ARDC to a group of functionally organized divisions. (The ARDC centers which, for the most part, were now absorbed by or subordinated to the divisions, had been organized essentially along geographic rather than functional lines, although AFOSR had been an example of a strictly functional organization even under the old system.) One new division that emerged was the Air Force Research Division, which included AFOSR, the European Office (ARDC), the Aeronautical Research Laboratory, and the Air Force Cambridge Research Laboratories--the four organizations in ARDC engaged in basic research. Basic research in the Air Force was thus now concentrated in one ARDC division.

The Air Force's research and development activities underwent another broad reorganization in April 1961. The outstanding feature of this reorganization was the combination of ARDC (minus AFRD) with those elements of the Air Materiel Command engaged in systems acquisition and related procurement functions to form the new Air Force Systems Command (AFSC). Had AFRD been allowed to remain with AFSC, its research functions would undoubtedly have been overshadowed by work on weapon systems. The Air Force decided, therefore, that it would be healthier for basic research to have its own organization apart from systems development. Thus AFRD, (still including AFOSR), was detached from ARDC, renamed the Office of Aerospace Research, and established as a separate operating agency with the procedural functions and responsibilities of a major air command. AFOSR was now an integral part of an organization devoted exclusively to research. It remains so today. ★

Dr. William J. Price became the Executive Director, AFOSR, in September, 1963. His past experience encompasses 23 years of continuous scientific work, including 3 years in graduate education, 6 years of basic and applied research, and 6 years as a manager primarily of basic-research in-house laboratory programs.

As Executive Director of AFOSR, Dr. Price has the management responsibility for the planning, procurement, and administration of a comprehensive contract/grant program of fundamental research in scientific areas of interest to the Air Force. He must also evaluate the significance of the results of this research in the light of Air Force application requirements.

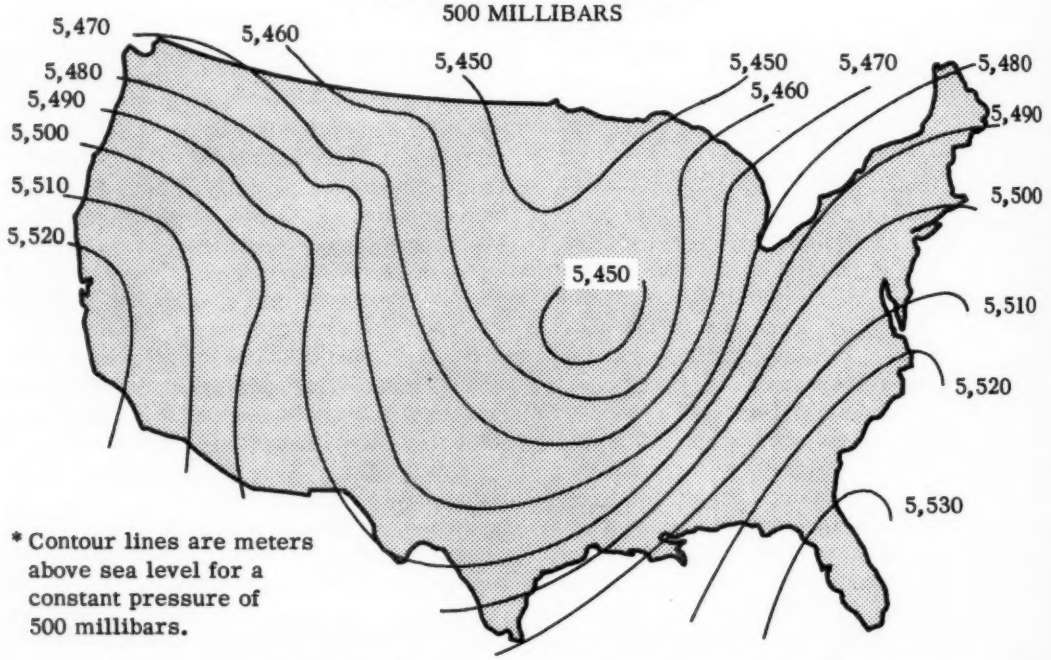
Before coming to AFOSR, Dr. Price was Chief Scientist at the Aerospace Research Laboratories, OAR, Wright-Patterson AFB, Ohio. He was born in Alexandria, Ohio, where he attended local schools and studied physics and mathematics at Dennison University. He received his M.S. and Ph.D. degrees from Rensselaer Polytechnic Institute in 1941 and 1948, respectively.

NEW STATISTICAL-DYNAMIC METHODS for NUMERICAL WEATHER FORECASTING

ALFRED CRANCER, JR., Directorate of Mathematical Sciences, AFOSR

The forecast of the height of high-altitude pressure fields over the northern hemisphere is of considerable interest to military and civil aviation. Currently, the height fields at three pressures are being forecast. The sea-level altitudes for the pressure fields of 850, 500, and 200 millibars are about 1500, 5500, and 13000 meters, respectively, above sea level. Knowledge of the high-altitude pressure fields is of great importance in forecasting the velocity of upper-atmospheric winds and minimum time for flight paths of aircraft.

PRESSURE CONTOUR CHART*
500 MILLIBARS



* Contour lines are meters above sea level for a constant pressure of 500 millibars.

The initial height fields are obtained from observations of the upper atmosphere. These observations are made twice daily by stations located throughout the northern hemisphere.

The prediction of the initial conditions is a problem in dynamics; thus dynamical methods have been developed to solve these problems. But since the data obtained from a limited number of observation points are subject to errors of observation, statistical methods can be used to supplement the dynamical methods.

Professor Richard H. Jones of Johns Hopkins University, working under Air Force Office of Scientific Research sponsorship, has obtained solutions of problems of great interest and importance to numerical prediction in weather forecasting. The first of three papers, Optimal Estimation of Initial Conditions for Numerical Prediction, gives a method for applying control-theory techniques to hemispheric predictions. Two important problems solved are:

(1) The development of a method for

applying the theory when the covariance matrices of the random excitation and observational error are unknown.

(2) The extension of results to the prediction of random fields rather than vectors.

A second paper, Exponential Smoothing for Multivariate Time Series, presents a variation of the estimating procedure. This enables the estimation to be carried out continuously as data become available.

The importance of this research to numerical prediction of weather is demonstrated in Professor Jones' most recent paper, An Experiment in Nonlinear Prediction, which was enthusiastically received by the American Meteorological Society. In this paper, he compares statistical-dynamical predictions with dynamical predictions for a group of problems which are simulated nonlinear time series. In every case the statistical-dynamical predictions show an improvement over the dynamical predictions. ★

UNCERTAINTY AND DECISION MAKING

DR. ROBERT E. ADAMSON
Directorate of Life Sciences, AFOSR

Before making a decision, one is likely to be faced with two types of uncertainty: first, which of several possible stimulus conditions exist; and, second, the choice of a response. The two types normally, but not always, coexist. Thus, in Southeast Asia, we are confronted with such problems as the disposition of communist troops and supplies, as well as with the problem of what plan of action we shall adopt in a contingency.

The interaction of these two forms of uncertainty and their relation to other variables in the decision process are currently being studied under Contract AF 49(638)-1441, at the Center for Research on Social Behavior, University of Delaware. This work is under the direction of Dr. John T. Lanzetta, Director of the Center.

Dr. Lanzetta and his associates have performed a number of experiments in which both stimulus and response uncertainty are varied in different ways. For example, in one case the information inputs to the subject are unpredictable, both increasing and decreasing uncertainty, whereas in another study, each information input reduces uncertainty by one bit. In both cases, it is possible to compare the objective uncertainty existing at each stage of the predecision process with subjects' estimates of uncertainty at the same stage.

Objective uncertainty is measured by:

$$H = \sum_{i=1}^{n} p(i) \log_2 p(i)$$

where p(i) represents the probability of the ith stimulus for stimulus uncertainty and the probability of the ith response for response uncertainty. Subjective uncertainty measures are based upon quantitative estimates made by the subject.

Comparisons of objective and subjective uncertainty indicate that subjects tend to overact, expressing a greater subjective uncertainty than is warranted. Dr. Lanzetta points out that such "over reaction" may have a functional value in mobilizing the organism for the decision task.

Additionally, it appears that subjective uncertainty fails to increase beyond the three-bit stimulus-response uncertainty level. This finding suggests a subjective correlate of a channel capacity for the organism with respect to uncertainty. The rate of increase of subjective uncertainty, however, varies for different subjects. This indicates a differential tolerance for uncertainty and reactivity to it in the decision process.

With respect to the decision process itself, different strategies are apparent, depending upon the nature of information inputs. When these are reliable, as in the case where each input reaches uncertainty by one bit, subjects appear to relate each new bit of information to the problem and make subdecisions as they go along--that is, they process the information on a continuous basis. On the other hand, when information is unpredictable in terms of increasing or reducing uncertainty, a constant amount of

time is spent in accepting information, and the subject appears to delay its processing until such time as he is ready to make a decision.

Two other findings are of interest. One is that, under conditions of high stimulus uncertainty, less time is spent in studying the problem, and there is a greater tendency to make information-search responses. A rational explanation for this is that the subject perceives that studying the problem as it is will not likely lead him to a solution. Additionally, Dr. Lanzetta suggests the possibility that high uncertainty increases the subject's state of drive, thereby reducing the latency of the information-search response.

Additionally, it seems that information-search behavior persists until a specific level (threshold) of uncertainty is reached, at which point the subject makes a decision. This takes place at about the one-bit uncertainty level and is fairly constant in a cross section of subjects.

Taken together, these findings indicate that the predecision period of information search and processing is a critical area for research in understanding the nature of decision making. They suggest that interactive effects between stimulus and response uncertainty, the nature of the inputs, and individual differences, all contribute to the decision-making process. ★

NEW RESONANT STATES OF ELEMENTARY PARTICLES

MAJOR JOSEPH E. GORRELL, Directorate of Physical Sciences, AFOSR

Collaboration between Professor Levi Setti's group at the University of Chicago and three European groups began in 1964 to investigate the interactions of K^- mesons with protons. The K^- meson beam was obtained from the CERN 28-Bev proton synchrotron and the interactions were observed using the SACLAY 81-cm liquid-hydrogen bubble chamber. The interactions investigated were for 20 different values of momentum transfer from 800 Mev/c to 1200 Mev/c.

Three hundred thousand pictures were taken in three dimensions of the bubble-chamber particle tracks which were produced by the interaction of the K^- mesons with the hydrogen nuclei (protons). The analysis of these pictures was divided among the collaborators, and is still in process. Professor Setti's group, which is supported by AFOSR, is analyzing all events of two-prong topology. These events consist primarily of K^- mesons scattered elastically from protons.

The analysis of bubble-chamber film is quite tedious and time consuming. The film must first be scanned, using special machines, to select those tracks which are of interest. The three-dimensional coordinates of several points along these selected tracks must then be precisely determined using an accurate measuring machine. The coordinate data are read into a computer which is programmed to calculate the kinematical parameters of the events.

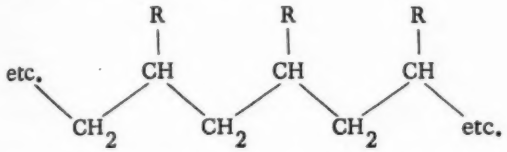
Preliminary analysis has revealed two new "resonances" or particles of masses 1765 Mev and 1820 Mev. Investigation of the 1820-Mev resonance has shown it to have a spin of 5/2, positive parity, and no charge. This particle is believed to be an excited state of the lambda particle whose ground state mass is 1115 Mev and has a spin of 1/2, positive parity, and zero charge. The other resonance of 1765 Mev, if it is confirmed by further analysis, is totally unpredicted.

This research is fundamental and important to the theoretical physicists in their attempt to understand the nature of elementary particles via symmetry schemes that predict multiplets of particles. It is, therefore, of utmost importance to identify and establish the quantum numbers of all resonances which can be produced by existing particle accelerators in order to determine whether or not they can be fitted within existing theoretical models. ★

The Spatial Configuration of Chain Molecules

DR. AMOS G. HORNEY, Directorate of Chemical Sciences, AFOSR

The usual way of writing the chemical formula of a long-chain polymer on the printed page conceals the most distinctive feature of its molecular geometry. Thus, the chemical structure of a vinyl polymer such as polyethylene (R = H) or polystyrene (R = C_6H_5), is usually written



as if the chain were stretched out in the form of a rod some 10,000 bonds in length. The spatial form of long-chain molecules almost always departs markedly from this simple representation owing to rotations about single bonds of the chain. In the "random-coil" configuration, characteristic of the chain polymer molecule as it exists in solution or in the amorphous bulk polymer, either rubbery or glassy, these rotations occur more or less at random. The spatial configuration of the chain molecule then takes on a form somewhat like that shown in Figure 1 representing the photograph of a model comprising a modest 500 bonds.

It is this capacity for irregular arrangement of their molecular configurations which endows long-chain polymers with properties required of plastics, elastomers, fibers and films. In the realm of living organisms, high polymers likewise provide the essential structural materials. Thus, the structure proteins--collagen of skin, bone and tendon; elastin of ligament, blood vessels and aortic tissue; and myosin of muscle--are the materials of construction in animals. Similarly, cellulose and related polymers provide the structural constituents of plants. The high extensibility of typical elastomers (including proteins like elastin) stems directly from the ability of a random-coiled polymer to undergo large changes in its spatial configuration through alteration of some of its bond rotation angles. The polymer can thus be deformed without damaging its chemical architecture. The recovery force in a deformed elastomer arises from the tendency of the chain molecules to restore the state of maximum randomness, or entropy.

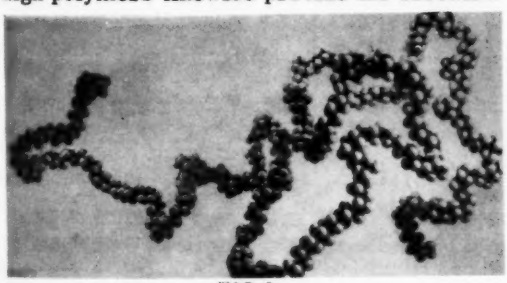


FIG.1

Understanding the configuration of polymer molecules is essential to the scientific interpretation of nearly all of those properties which distinguish polymers, both natural and synthetic, from other substances, and which equip them for their many uses. But how, one may ask, can a quality as ill-defined as the random configuration shown in Fig. 1 be characterized, bearing in mind also that thermal motions render any specific configuration transitory and subject to rapid change? A significant quantity for the purpose is the distance $\underline{r}$ between the ends of the chain comprising n bonds. This distance is also subject to large fluctuations. Hence, it is essential to deal with average quantities, and for this purpose a most useful average is the mean square, signified by $\langle r^2 \rangle$. The angle brackets denote averaging over all possible configurations of the entire chain of n bonds, weighting each configuration according to the probability of its occurrence.

Theoretical analysis of the problem reminded Dr. Paul J. Flory, Stanford University, an investigator for the Directorate of Chemical Sciences, AFOSR, of the mathematical theory of random walks. He points out that the polymer problem falls in this general category, but with certain special features of its own. For example, unlike a random walker, a polymer chain cannot cross itself for the obvious reason that two atoms, or two portions of a molecule, cannot

simultaneously occupy the same space. The path of the random walk may, on the other hand, intersect itself as often as chance may dictate. This mathematical problem will doubtless continue to intrigue abstract theoreticians for a long time to come. For our purposes, however, its difficulties may readily be circumvented by judicious choice of experimental conditions.

Dr. Flory notes that another difference from the classical random-walk problem enters from the restrictions imposed by valence bond angles, i.e., the angles between successive bonds of the chain. These, like the lengths of the bonds, are fixed within fairly narrow limits by valence forces. Moreover, bond rotations are limited by various interactions between atoms and groups brought into contact by rotations about bonds. Thus, unlike a random walk consisting of steps taken in directions which are unrelated one to the next, strong correlations exist between successive bonds of the chain; this correlation diminishes with distance along the chain, but may persist for several bonds at least. Hence, the direction of a given bond of the chain is severely limited by the directions of its immediate predecessors in the chain; and these correlations are prescribed by details of the molecular structure peculiar to the given example.

Much of Dr. Flory's work for AFOSR has been on the problem of relating the tortuosity of a given chain, as manifested for example in the value of $\langle r^2 \rangle$, to its structure. Relevant structural features are the bond lengths and bond angles; account must also be taken of the spatial interference between substituent atoms and groups caused by rotations about bonds of the chain. These are more difficult to ascertain, particularly in reliable quantitative terms.

According to Dr. Flory, the mathematical problem of establishing the connection between over-all chain dimensions (e.g., $\langle r^2 \rangle$) and the structure peculiar to a given chain molecule is much simplified by the fact that the energies associated with rotations about chemical bonds are periodic functions of the rotational angles. These "potential" functions usually possess several fairly well-defined minima. Consequently, it is a legitimate approximation to consider only those rotation angles corresponding to the energy minima. These often occur at rotations of 0^o, and of 120^o and 240^o measured from the planar form shown above. By thus restricting considerations to several discrete angles, statistical mechanical treatment of the chain molecule is rendered tractable. Methods developed years ago for hypothetical one-dimensional solids are here applicable to real systems, namely, linear polymer chains.

Dr. Flory's work shows that for a true random walk in which successive steps (bonds) are uncorrelated $\langle r^2 \rangle = nl^2$, n being the number of steps of length l. For a long polymer chain in which bond directions are locally correlated we have similarly

$$\langle r^2 \rangle = C_n n l^2$$

where C_n approaches a constant value C_∞ as $n \to \infty$. In all real examples studied to date, C_∞ is greater than the value unity applicable to a random walk; it is usually in the range of 5 to 10. The greater its value, the more extended the chain in its average random state, and therefore the less tortuous its configuration. Experimental values of C_∞ have been compared by Dr. Flory and co-researchers with those calculated theoretically from consideration of structure and steric interactions for some of the simpler polymer chains. They have established satisfactory agreement for polyethylene $-(CH_2)_n-$, polyoxymethylene $-(CH_2-O)_{n/2}-$, polyoxyethylene $-(CH_2-CH_2-O)_{n/3}-$, poly-(dimethylsiloxane) $\left[\begin{matrix} CH_3 \\ | \\ -Si-O- \\ | \\ CH_3 \end{matrix}\right]_{n/2}$, and for synthetic polypeptides $+CHR-CO-NH\rightarrow_{n/3}$. A start toward rational interpretation of the spatial configuration of chain molecules has thus been made.

Mathematical methods have had to be developed and refined by this Stanford Uni-

versity group for the purposes of these studies. Computers are essential, of course, to secure numerical results. However, computers alone are not enough. Consider for example the case of a chain of 10,000 bonds each being permitted to assume one of three rotational states. The total number of configurations for the chain as a whole is then $3^{10,000}$ or 10^{4771}. Enumeration of each of this enormous set of configurations individually would engage all of the computers in existence for centuries to come. It is at this point that mathematics effects drastic condensation, achieved without approximation. Thus simplified, an entire computation for a given chain may consume only a minute of computer time.

Recent results obtained by Flory and associates permit ready computation of C_n for all values of n, small as well as large. They are thus able to investigate the advance of $C_n = \langle r^2 \rangle / nl^2$ as it proceeds to its asymptotic limit with increase in the length n of the chain. These studies for the first time permit critical evaluation of various arbitrary models introduced in the past to represent the statistics of the configuration of polymer chains. Such studies are important for a proper understanding of elasticity and other physical properties of polymeric materials. Limitations of these models as a basis for treating polymer chains are becoming apparent, and it is hoped that a better basis for comprehending the properties of macromolecular materials can be provided.

★★★

The First International Conference on Physics of Solids at High Pressures

DIRECTORATE OF PHYSICAL SCIENCES, AFOSR

For those who are studying the physics of solids at high pressures, communication between the experimentalists in this area and theoretical solid-state physicists appears to be exceedingly poor. Under encouragement and sponsorship by the Division of Solid State Sciences, Air Force Office of Scientific Research (AFOSR), a committee was organized in the fall of 1964 for the purpose of holding a small conference to improve the much-needed communication. William Paul of Harvard, David Lazarus and Harry Drickamer of Illinois, A. W. Lawson of Riverside, R. M. Emrick and C. T. Tomizuka of Arizona, and Max Swerdlow of AFOSR met in Chicago and decided to invite a large number of leading theorists in solid-state physics to the conference, which was to be held in Tucson, Arizona.

Members of the committee were delighted to find enthusiastic support for the conference among theorists such as Harvey Brooks, Walter Harrison, J. M. Ziman, and S. A. Rice, to name a few. After all the detailed preparations were completed, the conference ran for 3 days beginning April 20, 1965, at the Arizona Inn in Tucson, and had 32 speakers and 175 participants. It opened with a message from Governor Goddard, and addresses by President R. A. Harvill of the University of Arizona, cosponsor of the conference, and Dr. William J. Price, Executive Director of AFOSR.

The first session was on the Fermi surface, followed in the evening by a session on the electronic properties of metals and semiconductors. The last paper of the evening session by Matthias stimulated a long and lively series of discussions on the nature of superconductivity. Two young Soviet physicists, Ponjatovskii and Iakovlev, each presented a brief report and discussion on the pressure effect on the properties of chromium, following a presentation by Mitsui who discussed the pressure effect on the Neel temperature of that material.

The second day began with a theoretical contribution on the stability of magnetic moments in rare-earth metals by Blandin of the University of Paris at Orsay, followed by a series of experimental papers on magnetism from the United States and Japan. Drickamer's report on the remarkable Mössbauer study of iron at very high pressures concluded this session.

The use of pressure to study imperfections in solids through diffusion measurements was initiated by Lawson and Nachtrieb some years ago in Chicago. At this conference other approaches, such as the electron spin resonance at high pressures, and also the optical spectroscopy of color centers at high pressures and low temperatures, were demonstrated to be significant tools of investigation. Numerous prepared discussions presented during the lattice-defects session also indicated that this area is indeed the one in which application of high pressures could significantly enhance understanding of the fundamental processes involved.

The third and last day of the conference was highlighted by a controversy between Jamieson of Chicago and Vereschagin of the Institute of High Pressure Physics in Moscow concerning the possible existence of NaCl to CsCl type transition in alkali halides at high pressures. For the last session of the conference, Swenson, who is spending a year in Sydney, reported on the P-V-T diagram of inert gases near $0^{o}K$ at high pressures. W. Kohn presented lucid arguments based on simple physical considerations on the electronic phase transitions. The last two papers consisted of the joint theoretical and experimental work by a Harvard group on the semiconductor-to-metal transition in V_2O_3 presented by Brooks and Paul.

Throughout the conference the air of informality prevailed, and it appears that a good deal was accomplished in improving the communication between experimentalists and theorists. The success of a conference of this nature, however, cannot be evaluated immediately in terms of who learned how much. It is doubtful whether an accurate evaluation can ever be made. Yet it seems certain that, for years to come, some of the numerous links established loosely among various concepts, disciplines and participants during this conference will develop into productive reality in the area of solid-state physics.

The proceedings of the First International Conference on the Physics of Solids at High Pressures are to be published by Academic Press. ★

Research Studies for Supersonic Combustion Ramjets

DR. BERNARD T. WOLFSON
Directorate of Engineering Sciences, AFOSR

The investigation of air-breathing engines for hypersonic flight has received renewed attention in the past few years. For hypersonic speeds, ramjets having various modes of operation have been considered. The basic difference between these modes of operation is associated with the combustion process used.

In the classical ramjet approach, the flow is decelerated by an inlet, and combustion occurs at subsonic speeds. This type of ramjet requires a very complex variable geometry inlet and nozzles whose complexity increases with flight speed.

Another mode of combustion presently being investigated for the Air Force by the General Applied Sciences Laboratory (GASL) under the direction of Dr. Antonio Ferri is supersonic combustion of the fuel and air, where the combustion is controlled by the mass diffusive mixing process. In the supersonic combustion engine, the entering air is decelerated by an inlet to a lower but still supersonic velocity, causing the local static pressure and static temperature to increase. For the high flight Mach number range (6 to 24) proposed for vehicles operating with this type of engine, the temperature of the air entering the combustion chamber is high enough to induce ignition of the fuel with which it is mixing.

Several important questions can be raised as to the practical possibilities of such a scheme for initiating and completing the combustion process efficiently. This efficiency is dependent on two fundamental factors: (1) the possibility of rapidly mixing the fuel and air and achieving reaction in a short length in spite of the high velocity flow, (e.g., approximately 10^3 ft/sec); and (2) the avoidance of shock formations either due to fuel injection or to the combustion process itself.

Supersonic combustion processes, in general, are controlled by a combination of

complex chemical and fluid mechanical phenomena. The processes of mixing and chemical reaction which take place in the burner are intimately connected, and in general the reactants first diffuse and then react chemically.

It is customary to introduce two characteristic times, one associated with the diffusion process or mixing time, t_D, and one with the chemical reaction or chemical time, t_{CH}. There are two extreme cases. If $t_D \gg t_{CH}$, (e.g., the time to complete the chemical reaction is much shorter than the diffusion time), the process is mixing or diffusion controlled. If, on the other hand, $t_D \ll t_{CH}$, the process is reaction controlled; and it can be considered as a system where mixing and diffusive effects are absent, e.g., at any point the system is composed of a uniform mixture of all species.

A substantial amount of research has already been accomplished in flow regimes associated with these two extreme possibilities, and experimental results have proved that combustion can occur efficiently in lengths of the order of inches, irrespective of the high flow velocities involved.

Looking now at the so-called chemically controlled reaction process ($t_{CH} \gg t_D$), it is evident that any study must be preceded by a detailed knowledge of the fuel-air reaction. In particular the hydrogen-air reaction (hydrogen gas being selected as the fuel for high-performance hypersonic ramjet engines) has been investigated in great detail. Sufficient information is already available to permit the determination of reaction times as a function of pressure and temperature with enough precision to make the estimates of performance reasonable.

Within the temperature history of the chemical reaction involved, two characteristic time periods can be distinguished. There is an initial time interval, usually called the induction or ignition delay time t_I, during which the temperature remains approximately constant and equal to the initial value of the mixture. After t_I, the temperature starts to rise to the final equilibrium temperature and a time t_R, termed the energy rise time, can be associated with this second phase. Evidently the total chemical time $t_{CH} = t_I + t_R$.

The ignition delay and the energy rise times can be estimated from the kinetic rates, and consequently the length of combustion chamber required for complete combustion can be determined, provided the flow velocity at the burner entrance is known. Most recent work, based on a better knowledge of reaction rates, has shown that supersonic combustion is still practical at flight altitudes in excess of 150,000 ft. (Note that the static pressure is an important parameter in determining the time for complete combustion as can be inferred from the equation for the energy rise time):

$$t_R = \frac{105}{p^{1.7}} e^{-1.12T_o/1000}$$

At lower flight altitudes, the initial temperatures and static pressure at the burner entrance are sufficiently high so that chemical times are reduced to the point where they are no longer significant. Because of fast reactions, the heat release takes place in a very short distance; and the design of the combustion chamber is dependent on the time of the mixing process.

As an illustrative example, the energy release takes place in a distance approximating a fraction of one inch in a typical trajectory at 90,000 feet. Evidently this is a situation where the diffusion process must prevail. Under these conditions, the flow field can be analyzed under the simplifying assumptions that chemical equilibrium occurs and that the length of flame including mixing and reaction can be very small even at very high velocities.

To minimize any losses in performance and to avoid localized regions of excessive heat-transfer rates, much higher than the average requirements compatible with structure, all possibilities of shock formation must be eliminated. Therefore, a suitable scheme for fuel injection is axial injection; that is, the fuel is injected parallel to the main stream. A considerable amount of theoretical and experimental work with actual

gases and high velocities of interest has been gathered in recent years on this basic problem of fluid dynamics. The conclusions are that the axial scheme provides an effective means of fuel injection and mixing.

Additional advantages are obtained with this method of injecting the fuel. In particular, it provides gaseous film cooling for the internal engine surfaces. For example, the high heat-transfer rates where the reaction zone approaches the wall can be avoided by successive slots. Also, it can produce useful thrust, which is an important factor for good performance at high Mach numbers.

Experimental work on spontaneous combustion characteristics of hydrogen injected into a supersonic stream has been performed in highly idealized combustion chambers and compared with theories developed for cases where the chemical process is the controlling mechanism, or where equilibrium chemistry prevails. Good agreement has been found between experiment and theory. Nevertheless, the theoretical analysis of an actual combustion process, (as required by the design of a practical burner), is a very difficult, if not an impossible task. In any realistic treatment of the flow field associated with combustion--viscosity, heat conduction and diffusion are equally important and in general these transfer phenomena occur as a result of both molecular action and turbulent motion. Since one is dealing with chemically reacting gases, the complete set of reaction rate equations in terms of the finite chemical reaction rate constants must be included. Continuity equations must be satisfied for each chemical species as well as for the mixture.

The complexity of the governing equations is so great that standard techniques of solving them on high-speed computing machines are impractical because of time-consuming computations. However, new mathematical techniques have been developed for handling the finite rate chemistry. These techniques have made fast and economical solutions possible; thus, the theoretical approach has become useful in predicting general features which are common to all combustion processes.

Recent studies have suggested that the speed range of using supersonic combustion could be extended also to lower flight Mach numbers, say (3 to 6). For these lower speed range conditions, the compression of air from ambient Mach numbers to flow conditions (appropriate to the burner entrance) does not increase the air temperature enough to ensure that spontaneous thermal ignition will occur. Some kind of external ignition source (pilot) must be employed to initiate the reaction locally after the mixing has taken place. If the heat produced by the local reacting zone is large enough to establish a favorable balance, the reaction will proceed, thus heating the combustible mixture and causing the flame to propagate. This case is said to be thermally controlled by the rates of the various reactions as well as by the diffusion of reaction initiators, e.g., thermally excited molecules and activated free radicals.

Preliminary experimental work has been performed at GASL, sponsored by AFOSR under Contract AF 49(638)991. The results confirm the feasibility of using supersonic combustion at relatively low supersonic flight Mach numbers, and provide a sound basis for the design of a practical engine operating in this combustion regime. ★

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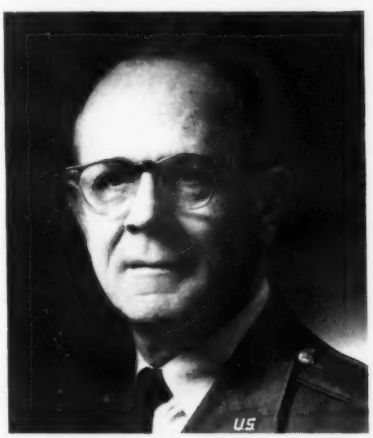
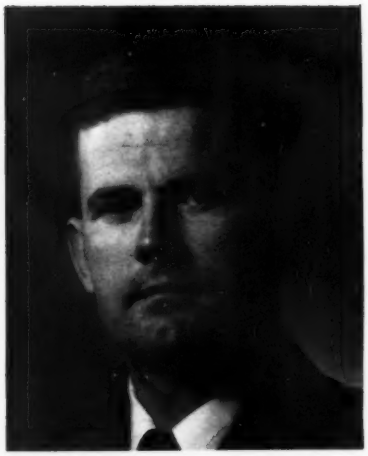
AFOSR's frequent contributors to the Review

Major Barnett R. Agins, as Chief of the Applied Mathematics Division, Directorate of Mathematical Sciences, AFOSR, manages contractual support of basic research in this area for the Air Force. Prior to his coming to AFOSR in July 1961, he was a project engineer at the Weapons Guidance Laboratory, WADC. He was responsible for the development of electronic warfare systems, including those for the B-58 and GAM-72. Major Agins is a native of New York City, and has a Master's degree in Electrical Engineering from New York University. He also holds a Master of Science degree in Mathematics from Stanford University and has done further course work toward a Ph.D. at that same institution.

Mr. William J. Best is the Chief of the Geophysics Division, Directorate of Physical Sciences, AFOSR. After specializing in geophysics at St. Louis University, where he received his M.S. degree in 1952, he served as an Air Force officer with the Air Force Atomic Testing Group which conducted and monitored field experiments in seismology for the detection of nuclear explosions. Subsequently, he was assigned to the Air Technical Intelligence Center, Wright-Patterson AFB, Ohio. There, from 1958 until his assignment to AFOSR in March 1961, he served as Chief, Geophysics Branch, Air Science Division, and as Chief, Manned and Unmanned Space-Vehicle Section, Missile Weapon Systems Division. Mr. Best retired from the Air Force in July 1964 as a Lt. Col.



Lt. Colonel Ralph W. Conners has been Chief of the Solid State Sciences Division, Directorate of Physical Sciences, AFOSR, since 1961. After graduating from the University of Dayton with a degree in Chemical Engineering (1936), Colonel Conners was employed by the Frigidaire Corp., Dayton, Ohio. He came on active duty during WW II and, after his discharge, served as a research chemist for Lowe Brøs. Co., Dayton, Ohio, until 1951. He was subsequently recalled to active duty and served in several capacities at the Materials Laboratory, WADC. In 1957 he became Chief, Materials Branch, Hq ARDC. Colonel Conners is a member of the American Chemical Society.



Captain John F. Gander has been a project scientist with the Mathematics Division, Directorate of Mathematical Sciences, AFOSR, since 1963. In this position, he participates in managing the AFOSR program of basic research in pure mathematics. This program is intended to produce new knowledge in mathematics of potential application to Air Force technology. Captain Gander was born in San Francisco, California. He has a B.S. and M.S. from Florida State University. He has the aeronautical ratings of Navigator and Aircraft Performance Engineer.

Dr. Marshall C. Harrington came to the General Physics Division, Directorate of Physical Sciences, AFOSR, in April 1962 as a project scientist. A graduate of Princeton University, with highest honors (1926), Dr. Harrington received his A.M. in Physics (1927) and Ph.D. in Physics (1932) both from Princeton University. Subsequently, he served as an instructor in physics and as a research assistant at the same university. From 1943-51, he was chairman of the Division of Sciences at Drew University. He later accepted a position as physicist for the Department of the Navy, and headed the Fluid Dynamics Branch at the David Taylor Model Basin from 1957 to 1960. Prior to his coming to AFOSR, Dr. Harrington served as the Contract Research Administrator for the Bureau of Ships Fundamental Hydromechanics Research Program.

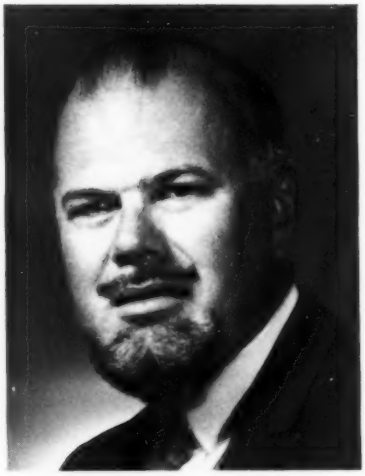
Mrs. Rowena W. Swanson has been a project scientist and research administrator with the Directorate of Information Sciences, AFOSR, since 1961. She worked for four years at the U.S. Patent Office before coming to AFOSR, serving as a patent research specialist in the design and implementation of information storage and retrieval systems for the patent literature. Mrs. Swanson is a graduate of the Catholic University of America, where she received a B.S. degree in Chemical Engineering (1949). In 1953, she received a Juris Doctor from the George Washington University Law School.

contributors

Mr. Max Swerdlow was associated with the National Bureau of Standards (NBS), Wash, D.C. for 17 years, both as a physicist and as Assistant Chief of the Constitution and Microstructure Section. He has a B.A. in Physics from Brooklyn College, and has done extensive work at the NBS Graduate School. Mr. Swerdlow accepted a position with AFOSR in May 1957 as a project scientist with the Solid State Sciences Division, Directorate of Physical Sciences. He is an active member in 6 professional societies, and has been a past president of the Electron Microscope Society of America and the Washington Society for Electron Microscopy.

Dr. Alfred Weissler was appointed to the staff of the Directorate of Chemical Sciences, AFOSR, in February 1962. His assignment as a project scientist capped a varied scientific career as researcher, administrator, writer, and teacher. Previously, he had worked for the Army, Navy, and the National Institutes of Health, and had taught graduate courses at American University and the Department of Agriculture Graduate School. Dr. Weissler has worked in various subdivisions of chemistry, in biomedics, in physics and in biophysics. Presently, he is guiding the Directorate of Chemical Sciences' programs in aerospace chemistry and physical chemistry, and is editor of AFOSR's annual Chemistry Program Review. He received his Ph.D. in Inorganic Chemistry from the University of Maryland in 1946.

Dr. Bernard T. Wolfson has been a project scientist with the Propulsion Division, Directorate of Engineering Sciences, AFOSR, since 1960. He has the responsibility for planning, organizing and managing externally sponsored research programs with universities and industry in the area of combustion dynamics. Since 1942, when he joined the Air Material Command at Wright-Patterson AFB, Ohio, Dr. Wolfson has worked in areas concerned with various phases of energy transtormation and utilization, and aircraft, rocket, missile and propulsion design. He was graduated from the Armour Institute of Technology with a B.S. in Chemical Engineering (1940). He received his M.S. (1950), and his Ph.D. in Chemical Engineering (1962), both from Ohio State University.



Dr. Harold Wooster is Director of Information Sciences, AFOSR. His Directorate has the responsibility for managing a multidisciplinary basic-research program in the advanced non-numerical uses of computers in such areas as pattern recognition; lexical processing (including data or information processing, storage and retrieval, and translation); encoding for communication and control; and decision-making. Dr. Wooster joined AFOSR in 1956. Prior to that, for nine years, he worked at the Mellon Institute in Pittsburgh as Senior Fellow on a Food Varieties Fellowship. He has an A.B., magna cum laude, from Syracuse University (1939), an M.S. in Physiological Chemistry (1941) and a Ph.D. in Physiological Chemistry (1943), both from the University of Wisconsin. He has a great number of publications to his credit, and is a member of various professional and honorary societies including Phi Beta Kappa, the American Chemical Society, and the American Documentation Institute.

ASSISTANT FOR RESEARCH SERVICES, AFOSR

Mr. David L. Arm is Assistant for Research Services, Office of the Executive Director, AFOSR. Before coming to work with the Air Force, Mr. Arm acquired extensive experience in the fields of education and industry. He has been Director of Personnel at Purdue University, Chairman of the Mechanical Engineering Department at Iowa State College, and Dean of the School of Engineering at the University of Delaware. After four years as Director of Industrial Safety for the National Safety Council he went to Holloman AFB, N Mex., where he became Chief of the Orbital Mechanics Division, Air Force Missile Development Center. In March 1961, he transferred to AFOSR. In his present position, he maintains liaison with the academic community, Air Force laboratories, and AFSC STLO's, arranges visits to major commands, and provides speakers for AFIT and the Air University. Mr. Arm also directs the annual AFOSR Scientific Seminar, and is responsible for the AFOSR inputs to the OAR Research Review.

ANTHROPOMORPHS VIA ADAPTIVE THRESHOLD LOGIC

ROWENA SWANSON, Directorate of Information Sciences, AFOSR

In the beginning was a machine that performed a function exclusive theretofore to nature. And the machine was built by man. And man saw that the machine was good. And man built another machine. And man found that he could extend his horizons and enlarge his capabilities with each machine. And then man wondered--could he build a machine that could think?

The drama and the controversy of anthropomorphizing machines are faintly reminiscent of the furor caused by considering man as a descendant of the apes. Away from the din, in the university and industry research labs, is a corps of scientists examining what we might call the "pattern-recognition problem." If intelligence is at least, in part, learning to identify patterns and relating what has been learned to new configurations, the pattern-recognition problem is a problem of being able to describe the steps that are involved in these operations in terms amenable to machine specifications. To be sure, therein lies the rub. The thermostat is an "intelligent" device because it recognizes changes in temperature, regulates a system on the basis of this recognition, and continuously adapts to environmental change. The intelligence of the thermostat resides in the physico-chemical properties of metals or fluids. Back to the drawing boards, then, to find the properties of thought.

From the drawing boards, since the World War II research on computers, have come such overviews as are reported in the Proceedings of the Josiah Macy Conferences on "Circular, Causal, and Feedback Mechanisms in Biological and Social Systems" (1), and as are amplified in studies such as those in Princeton Annual No. 34 ("Automata Studies") (2) and the Advances in Computers series. (3) Practical solutions, perhaps only at the first level of ultimate achievements, are presently being evolved for such military applications as signal detection, interpretation of radar displays, guidance and reconnaissance systems, and command and communication systems. Concepts and refinements of concepts are coming from these investigations. The learning of various tasks is being encapsulated in rigorous descriptions, and procedures are being developed to incorporate learning into operational systems. The feasibility model has, in some instances, gone to full scale. (4)

In one AFOSR-sponsored program, Tim Ewald of General Electric (Tempo) has been studying the applicability of adaptive threshold logic to several pattern-recognition problems. (5) Threshold logic elements can be trained in the following way: a set of binary inputs and the desired output are fed into a system. If the actual response of the system does not match the desired output, an adapt signal is fed into the system. The system then adjusts each input gain and the threshold firing level sequentially in a direction that reduces the error of response by $1/n+1$, where n is the number of input signal channels. The modifying procedure is continued until the desired output is obtained. This learning operation is repeated for other input sets until the desired switching systems are realized. At the end of the training period, the adaptive switching system is able to classify a new input to the system and give the appropriate output signal.

In one simulation of an adaptive threshold logic system at Tempo, weather forecasting by machine as good as human forecasting was obtained for 24-hour forecasts; machine predictions were better for 36-hour forecasts. The system was trained on input data consisting of surface pressures and rate-of-change of pressure over a 5-million-square-mile area (San Francisco). An analysis of the weights which were established by the above-described iterative procedure gave, as a by-product, a systematic method for

evaluating the importance of meteorological parameters in weather prediction. The output data indicated how the number of sample points could be reduced without appreciably affecting the performance of the predictive system.

Mr. Ewald is now examining the possibility of using adaptive threshold logic to distinguish multiple radar targets in marginal return signals. He is complicating the problem by seeking algorithms by which the system can teach itself to assign categories to the input data. A small test program which simulated the interaction of two targets with a monopulse radar distinguished one target from the other when they were only 0.4 beam width apart at a 20-db. signal-to-noise ratio. Greater separation would be required, however, to accurately describe the angular position of two targets. Other studies with different decision criteria point to improvements in displayed results. The broad objective in this investigation is to gain insight into how various adaptive systems function, and discover the degree to which complex information can be separated into discernible categories.

Mr. Ewald's work is an outgrowth of his interest in neural networks. (6) He hypothesizes that a neural-network type of information system learns to generalize its past experience and stores an algorithm enabling it to react immediately to input stimuli without searching through its memory to match current stimuli with past patterns. The process by which specific bits of information existing in specific places are aggregated and manipulated, uses inductive techniques of statistics (as trained into the adaptive switching circuits) as well as the deductive circuit logic most generally used in present-day computers. Adaptive threshold logic devices have been shown by Dr. Bernard Widrow and others at Stanford University to be useful for analyzing such wave forms as those of vectorcardiograms and natural speech. (7) Mr. Ewald's study of self classification by threshold logic should be another step toward solving the problem of describing complex nonlinear relationships such as those existing in biological and physical systems. This research on adaptive-logic computer elements and associated theorems and devices may provide fundamentals for a new generation of machines which can be taught by men to perform recognition operations like men. Such machines as tools for man presage a new age in man's exploration of his surroundings and exploitation of his capabilities. ★

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(4) *Reported at the IEEE Convention in New York in March, for example, is the extensive use of computers for direct digital control of production processes. To be sure, only fixed control loops are built into most of the current systems, but other features of optimization are not only being considered but are viewed as economically feasible. See Chemical & Engrg. News, 5 April 1965, pp. 48-49.*

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Behavior of Niobium-Tin Superconductors in High Magnetic Fields

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Directorate of Physical Sciences
AFOSR

Long-awaited information on the behavior of superconducting materials in intense magnetic fields has been obtained by scientists at the AFOSR-sponsored National Magnet Laboratory (NML) at MIT (1). The measurements were possible because of a record-breaking magnet capable of generating sustained magnetic fields of 255,000 gauss. This magnet, which uses 10 million watts of power and 2,000 gallons of water per minute for cooling, was announced November 6, 1964 (2).

The measurements have established the upper-critical field at 220,000 gauss, and have determined the critical currents obtainable in a number of different commercial niobium-tin wires. In addition to the applied aspects of the measurements, the detailed structure of the data is of great interest to the physics of high-field superconductivity. The original measurements were taken by D. Bruce Montgomery of NML and William Sampson of the Brookhaven National Laboratory. Subsequent measurements have been made in cooperation with Radio Corporation of America and General Electric.

Superconductivity is a zero electrical-resistance state exhibited by some materials at temperatures near absolute zero. The technological implications of zero-resistance materials promise high magnetic fields requiring no power for their generation, transmission of power with no losses, highly efficient electrical machinery, and even electromagnetic propulsion and shielding from harmful cosmic radiation for space vehicles. Without knowledge of the critical fields and critical currents, however, the practicality and economics of such devices could not be estimated.

Superconductivity has been recognized for 50 years; but until 1961, when Bell Telephone Laboratories (3) made a fundamental contribution to the art of making superconducting materials, no materials were available which would remain superconducting in a usefully high magnetic field. One of the intermetallic compounds made in 1961, niobium-tin, (Nb_3Sn), had such an impressive ability to remain superconducting in a magnetic field that no one could produce a high enough field to destroy its superconductivity. Speculations ranged from 180,000 gauss to 350,000 gauss. The new NML magnet has now established this limiting field, called the upper-critical field, at 220,000 gauss.

While it is theoretically possible to make a magnet of the superconducting material to test itself, it would require massive amounts of the expensive material ($1,500 per pound). With the NML magnet available to the entire scientific community, small amounts of the material can be made and tested to find the optimum materials. Small magnets of the new materials can also be made and operated inside the large NML magnet to study the behavior of relatively long lengths of the materials.

The maximum current that a superconducting wire will carry is a function of the magnetic field it is exposed to, and is called the critical current. It is important to establish these critical currents as a function of field, since they determine how much material must be used to build practical devices. The critical currents are much more sensitive to metallurgical variables than the single-value upper-critical field, and the manufacturing conditions are set to maximize these currents. This requires the testing of a large number of samples to determine optimum conditions.

The superconducting measurements program that has been carried on in the 250-kG magnet and companion 110-kG and 150-kG magnets at the National Magnet Laboratory has resulted in major improvements in wire characteristics, and has illustrated that material can be tailor-made for high stability

in low fields or high current capacity at high fields. The critical fields of the Nb_3Sn materials tested ranged from 190 to 220 kilogauss and the critical currents, over a 4 to 1 range. The critical current-critical field characteristics of one of the highest current-density materials developed to date are shown in Figure 1.

Now that measurements have been made up to the upper-critical field, the economics of very-high-field superconducting magnets can be estimated. If we base the economics on the current price of $1500/pound and the best material measured (Fig. 1), we can estimate the cost of a 1-inch bore (3 cm) solenoid as a function of field strength. Figure 2 gives the estimate of wire cost for the condition of a single, 2-, 3-, and 4-section magnet. The multiple-section magnet allows sections exposed to lower fields to carry more current and, therefore, produces more field for a given amount of wire. Each section, however, requires a separate power supply. The steepness of the curves illustrates the rapidly increasing costs as the upper-critical field is approached, and it seems unlikely that fields beyond 185 kG will be achieved in an all-superconducting niobium-tin system. The amount of material required is approximately proportional to the square of the inner diameter, and costs therefore also rise rapidly for increasing bore size.

The requirements shown in Figure 2 should be thought of as an idealized minimum based on the assumption that all the wire will be as good as the best that has been tested, and that such high current densities could be tolerated in a large volume magnet. Major development programs would be necessary before success would be assured and a more realistic price tag attached. Several very

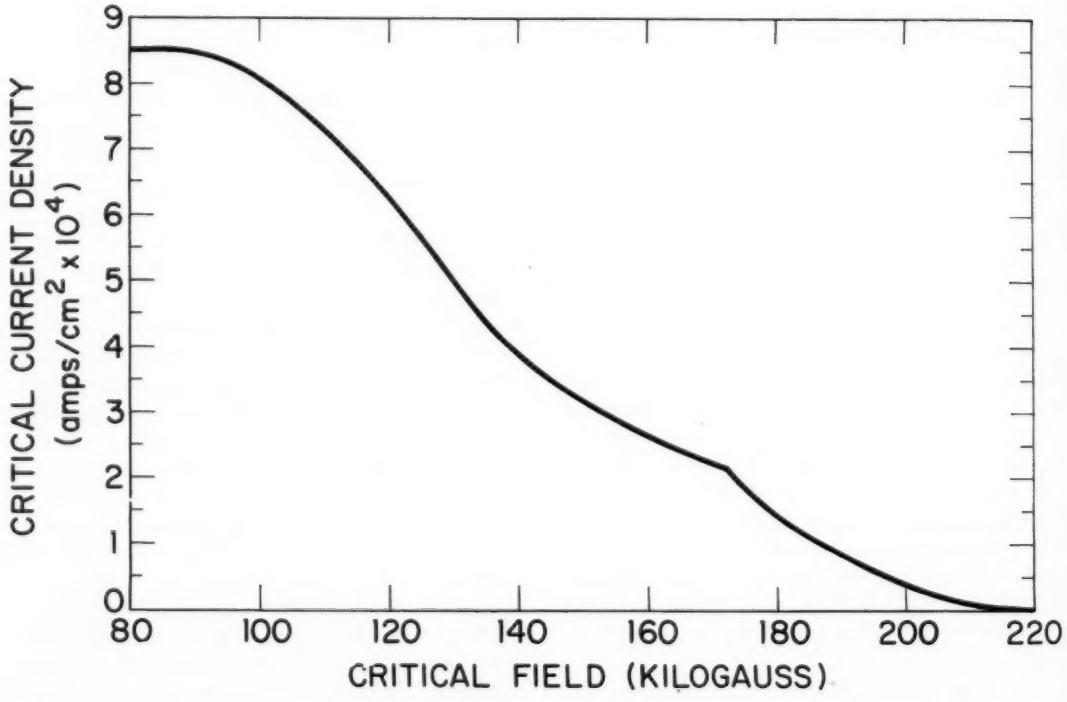

Figure 1. Critical current-critical field characteristics of a particularly high current density .027-inch-diameter Nb_3Sn wire. The curve represents the current density in the wire that will destroy superconductivity at a given field at 4.2 degrees K. The wire was supplied by the General Electric Company.

successful lower field superconducting magnets of Nb_3Sn have been built: a 1-inch bore 112-kG solenoid (4) and a 1/4-inch bore 132-kG solenoid (5) were recently announced. As part of its goal to achieve the highest practical superconducting field, the National Magnet Laboratory plans to use solenoids similar to these as insert coils in conventional copper magnets to achieve fields of 175 kG. These combination magnets require less power than an all-copper system, and less superconducting materials than an all-superconducting system. Eventually, Nb_3Sn materials will be used in large volume magnets surrounding copper magnets to achieve the highest possible fields.

In addition to the interest in the high field applications of niobium-tin, there is considerable interest in the physics of high field superconductivity. A significant advance in understanding the behavior of high superconductors was made when Kim, Hempstead, and Strnad (6) showed that the critical current characteristics were determined largely by

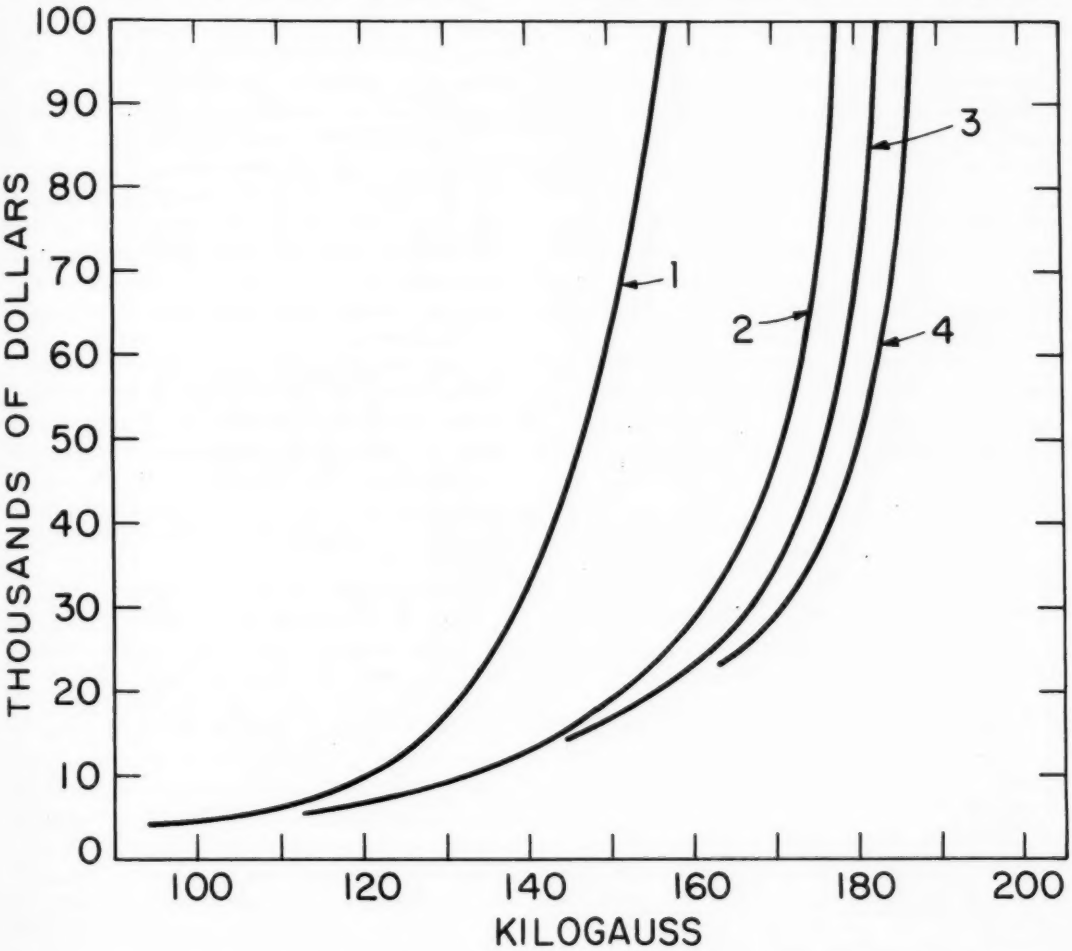

Figure 2. The cost of superconducting wire required to produce a 3-cm i.d. magnet capable of generating a given field between 90 and 185 kG based on the wire characteristics of Figure 1. The .027-inch-diameter wire is assumed wound 152 turns/cm^2 and priced at $9 per meter. The 4 curves represent single, 2-, 3-, and 4-section windings where each winding is to carry the maximum current as determined by the field at that winding.

the ability of a given material to stabilize the macroscopic flux distribution in the wire against the Lorentz force H x I (the product of magnetic field strength and current). According to the simple theory H x I should be a constant. The data taken in the high-field magnet indicates that the H x I product is constant below 100 kG but, at higher fields, shows a relatively long transition zone where the product is decreasing. Near the upper-critical field a sharp change in characteristics is noted, and it is suggested that this represents control of the critical currents by intrinsic properties of the material such as the energy gap rather than by the H x I properties. The study of both of these new zones, as well as the variation of the upper-critical field will yield significant new understanding of intermetallic hard superconductors. Strnad, Hempstead, and Kim (7) have recently made use of the flow of flux under Lorentz forces to illuminate the nature of the upper-critical field. These flow-type measurements are now being made on niobium-tin in the 250-kG magnet.

The 250-kG magnet will soon be used to study other very-high-field superconductors. Vanadium-gallium is one of the most interesting intermetallics, since it may have an upper-critical field higher than that of niobium-tin. ★

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PLASMA ACCELERATION BY ELECTRON CYCLOTRON RESONANCE

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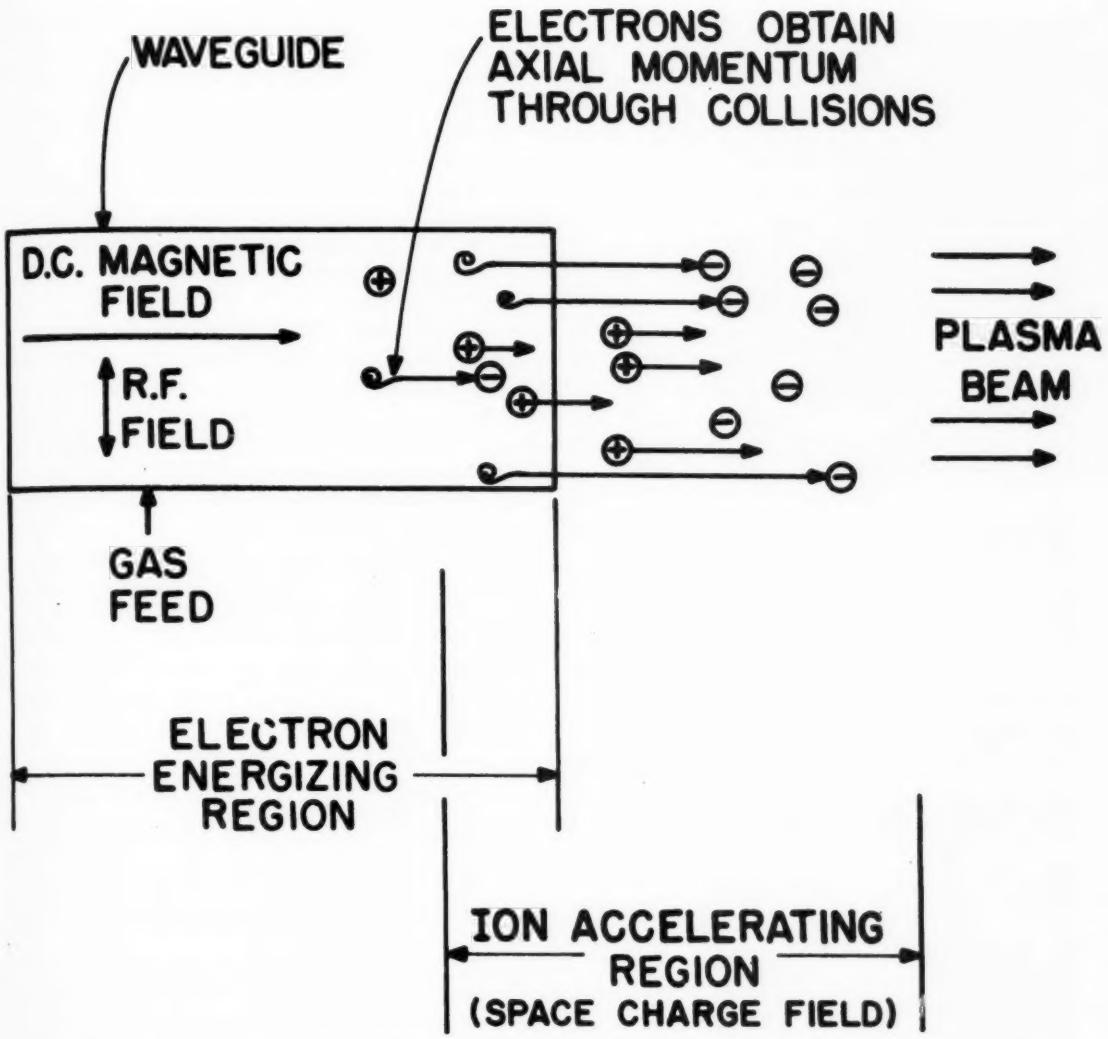
Directorate of Engineering Sciences, AFOSR

Under certain conditions, electromagnetic waves transfer some of their energy preferentially into the medium through which they propagate. In the case to be considered, the medium consists of a plasma, and the energy-transfer process results in heating of the electrons. The phenomenon is called electron cyclotron resonance, and can be compared to a child on a swing. In reaching a maximum, the swing is pushed a bit harder each time until the desired height is achieved. In the case of electrons, the swing goes over the top, and energy is added during each revolution. When the driving force is matched properly with the electron cyclotron frequency, energy is transferred to the electrons in the plasma.

The experimental apparatus consists of a wave guide, in which there is impressed a radio frequency discharge. An axial magnetic field is created by a solenoid outside of the wave guide. The plasma is formed by the ionization of mercury vapor in the discharge region. A schematic of the apparatus is shown.

For the sake of clarity, operation of the device is described in three regions: the electron heating region, the ion accelerating region, and the plasma beam. While the transition from one region to the next is not as clear-cut as indicated in the sketch, the phenomena occurring in these regions are quite different. Consequently, this model should prove useful in getting a physical picture of the over-all process.

In the electron heating region, free electrons from the ionized mercury vapor are heated by cyclotron resonance in phase with the applied R.F. field. The ions remain "cool" inasmuch as they do not couple to the R.F. at the applied frequency, and because they do not undergo many collisions. The final energy of the electron is influenced by the collision frequency which reduces the



SCHEMATIC DIAGRAM OF ELECTRON CYCLOTRON RESONANCE PLASMA ACCELERATOR

energy gained to the extent that it shifts the electron out of phase with the driving R.F. field. Taking into account coulomb and electron-neutral collisions, the resultant electron temperature is about 15 ev/particle on the average.

In the ion accelerating region, because of the strong magnetic field, the transport properties of the electrons parallel to the magnetic field are very different from those normal to it. The mean free path and diffusion coefficient of electrons parallel to the field are the same as for field-free space, and depend essentially on temperature. Across the field lines, electron diffusion is collision controlled, and, because the density is low, electrons are confined to steps of a Larmor radius. Thus, axial electron diffusion is about 1000 times greater than across the field, and establishes the flow. Ions, on the other hand, relatively unaffected by the magnetic field, are free to diffuse to the walls of the wave guide. In order to maintain total charge equilibrium, equal numbers of ions

and electrons must leave the system. As the electrons are heated, those in the high energy tail of the distribution begin to leave the machine through the open end of the wave guide. This gives rise to a potential gradient in the axial direction which accelerates the ions. Only the highest energy electrons participate in the net efflux; the remainder fall back into the discharge.

It is interesting to note that if the wave guide were open at both ends, no net thrust would be developed. By closing one end, particles streaming to the left in our figure strike the wall and transfer momentum to the wave guide.

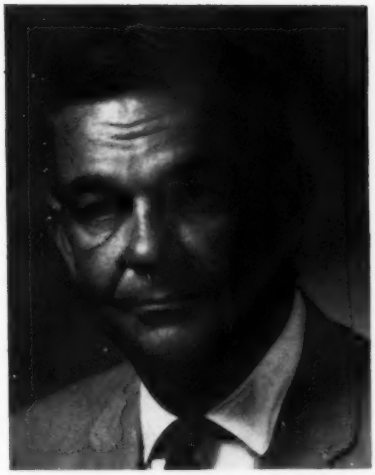
At the outer boundary of the potential fall, the plasma beam becomes fully established as the ion and electron fluxes are equal. In the experiment, measurements were made of the plasma potential, floating potential, electron temperature, and plasma density in the discharge and beam regions. Beam ion current and energy distribution are used to calculate the efficiency which varies with absorbed R.F. power. Efficiencies as high as 30% have been obtained at low power. An ion energy analyzer is used to measure ion current and energy distribution in the beam. This device consists of a collector electrode in a Faraday cup which collects the ions which have first fallen through a predetermined potential drop. The potentials are measured using Langmuir probes. Experimental results indicate that the kinetic energy of the ions, electron temperature, and plasma potential gradient are in good agreement with the theory.

This research is significant because it provides considerable information on an accelerating mechanism in plasma. It was shown that this ion accelerating mechanism, employing a space charge potential gradient set up by energetic electrons, is equivalent to the familiar electrostatic acceleration through a potential of about 70 volts. The beam, however, is neutral. Continuous operation for many hundreds of hours has been achieved at absorbed power levels up to 0.5 Kw. The research was supported under AF 49(638)1342 with the RCA Laboratory, Princeton, New Jersey, under the direction of E. C. Hutter. ★

SOME OF THIS MONTH'S CONTRIBUTORS TO THE REVIEW

other contributors to this issue are shown under "frequent contributors"

Dr. Amos G. Horney was appointed Director of Chemical Sciences, AFOSR, in October 1959. He brought with him a wealth of varied scientific, engineering and management experience from industry, the Government and the academic environment. Dr. Horney has management responsibility for planning, selecting and administering a grant and contract program in fundamental chemical research areas of interest to the long-range mission of the Air Force, and for interpreting chemical research accomplishments for the maximum benefit to the Air Force of the future. He has an A.B. in Chemistry (1930) from Earlham College, Richmond, Indiana, and an M.S. in Chemistry (1932), an M.A. in Education (1933), and a Ph.D. in Chemistry (1937), all from Ohio State University. He received Outstanding Civil Service Performance Ratings in 1949, 1955, 1957 and 1960, and has a great number of publications to his credit. Dr. Horney is also a member of a number of professional societies, including the American Chemical Society, and the American Association for the Advancement of Science.



Dr. Robert E. Adamson has been Deputy Chief, Behavioral Sciences Division, Directorate of Life Sciences, AFOSR, since June 1964. Prior to that he was a systems application manager in industry and an assistant professor of experimental psychology in the academic world. Dr. Adamson has a B.A. (1948), an M.A. (1949) and a Ph.D. (1952), all from Stanford University. He is the author of numerous publications on psychology and the design and implementation of large-scale computer-based systems, and their implications for management. He is a member of several professional societies, including the American Psychological Association and the American Society for Public Administration.

Mr. Alfred Crancer, Jr. joined the Mathematics Division, Directorate of Mathematical Sciences, AFOSR, as a project scientist and mathematical statistician in September 1964. Prior to that he worked as Chief Statistician with the Aerospace Industries Association in Washington, D.C., and as a mathematical statistician with the U.S. Department of Agriculture. Mr. Crancer has a B.S. degree from Arkansas State College (1955), and an M.S. degree from American University (1963).

Major Joseph E. Gorrell joined the staff of AFOSR in 1964 as a project scientist with the Nuclear Physics Division, Directorate of Physical Sciences. He is a graduate of the United States Military Academy (1948), from which he received a B.S. in Military Engineering. He also has an M.S. in Nuclear Physics from Ohio State University (1953). Prior to his coming to AFOSR, Major Gorrell completed his course work at Ohio State University for a Ph.D. degree. His previous assignments have been with the Air Force Special Weapons Center at Albuquerque, New Mexico, and the Hq Air Defense Command in Colorado. He also has had pilot training, and is a member of Sigma Pi Sigma, physics honor society.

Major Russell G. Langlois has been a project scientist with the Propulsion Division, Directorate of Engineering Sciences, AFOSR, since 1964. Prior to that he was Chief of the Flight Sciences Division, European Office of Aerospace Research, OAR, Brussels, Belgium. He has also been a light bomber pilot, and an aircraft commander with the 314th Troop Carrier Wing in Germany. Major Langlois received a B.S. in Physics from the University of New Hampshire in 1951. He was selected as the outstanding young scientist of the Washington area in 1961 by the Washington Academy of Sciences. He has several articles to his credit.

Dr. William L. Ruigh came to AFOSR as a project scientist with the Directorate of Chemical Sciences in April 1961. His work is particularly concerned with those areas of basic research involving the generation of new concepts and principles in inorganic chemistry and the synthesis of compounds containing novel atomic arrangements. Dr. Ruigh received his Ph.D. in Organic Chemistry from Princeton University in 1932. His varied career in the chemical sciences' area includes nine years with the Air Force. He was a research chemist at the Aerospace Research Laboratories, OAR, before coming to AFOSR, and recently spent five months as Visiting Research Scientist with the Norwegian Defense Research Establishment.

CHEMICAL LASERS

DR. WILLIAM L. RUIGH, Directorate of Chemical Sciences, AFOSR

The field of chemical lasers progresses with almost the speed of light. To illustrate the rapid progress in this area of science, we quote a statement from page 23 of the 25 Jan 65 issue of Chemical and Engineering News: "A Chemical Laser that operates successfully has yet to be built, and not all workers in the field are optimistic about the prospects." It was only two weeks later that the February 8th issue of the same magazine was headlined both on the cover and on page 38 with: "Chemical Laser Efforts Broaden Scope of Laser--Operational Chemical Laser Developed at Berkeley is based upon excita-

tion by a chemical reaction." The article discussed the recent report by J. V. V. Kasper and Dr. G. C. Pimentel of the University of California, Berkeley who, under a Directorate of Chemical Sciences, AFOSR grant, succeeded in obtaining laser emission from the chemical reaction $H + Cl_2 \rightarrow HCl^* + Cl$. The energy of the laser light is actually derived from the chemical energy released when hydrogen and chlorine react explosively when triggered by light.

The chemical laser just discussed is a step in advance of an earlier "chemical laser" also discovered by Pimentel based on the dissociation of methyl iodide by an intense flash of light. In Pimentel's "Atomic Iodine Photo-Dissociation Laser," Kasper and Pimentel, Applied Physics Letters, 5, 231, 1964, the energy from the reaction came from an intense high-energy xenon flash. The excited methyl-iodide molecules dissociated with bond rupture, and the resulting excited atomic iodine atoms in the $^2P_{1/2}$ state were produced in sufficient excess over those in the $^2P_{3/2}$ ground state to permit stimulated emission or actual coherent laser light when reacted in a suitable laser cavity. (Just recently, Pimentel and his associates have uncovered the evidence that this same laser emission has been found in the photolysis of six other alkyl iodides.) The principle of a "photodissociation laser" is that stimulated emission occurs as the result of bond rupture, although the initial energy from the photoflash is utilized to supply the energy for the excited inverted population and the resulting burst of coherent stimulated emission. In other words, the excited molecule of methyl iodide acts as a temporary reservoir for the flash energy, and the dynamics of bond rupture determine the population inversion. In the case of the hydrogen-chlorine reaction, the energy is essentially derived from the heat of the chemical reaction itself.

There is an interesting discussion of "Chemical Lasers" in the April 1965 issue of the Scientific American. In this short note, an attempt is made to define what is meant by the term, "chemical laser." The note includes the controversial statement that "Some workers feel the term 'chemical laser' should be reserved for a device in which the chemical reaction is self-sustaining. Such a laser is feasible in principle but has not yet been built." In this definition, the term "self-sustaining" is a key word and thus defines a chemical laser in limited terms of an elapsed time of operation and decay or growth characteristics of the reactions. We offer a point of view which differs from this statement, and consider Pimentel's HCl laser to be a true chemical laser. However, it must be admitted that there is a great deal of room for improving the efficiency of this or other chemical-laser reactions to produce coherent light.

The two chemical lasers discovered by Pimentel resulted from the use of a new tool or instrument he and his colleague, Dr. K. C. Herr, developed. This instrument is the rapid-scanning infrared spectrophotometer constructed by Pimentel with AFOSR funds. The heart of the instrument is an extremely sensitive, ultrafast-response, zinc-doped, germanium detector and a high-speed (10,000 rpm) rotating Littrow mirror. These elements, combined with a conventional Perkin-Elmer 12C monochromator, associated timing devices and an oscilliscope display tube have achieved scan rates of 1000 cm^{-1} per 100 microseconds through the region 5000-650 cm^{-1}.

The spectrophotometer makes possible for the first time infrared studies of extremely fast reactions such as the free-radical reactions occurring after flash photolysis, hitherto studied only in the ultraviolet, visible, and near-infrared due to limitations of the photographic plate. The fastest previously described infrared spectrometers either scanned an equivalent region 100 times slower, or a narrow region of 30 to 40 cm^{-1} in a comparable time. The optical path of the spectrometer is illustrated in Figure 1, where S,F,L,D,μ,C, and Q identify the IR source, the flash lamp, rotating Littrow mirror, detector, metal mag-

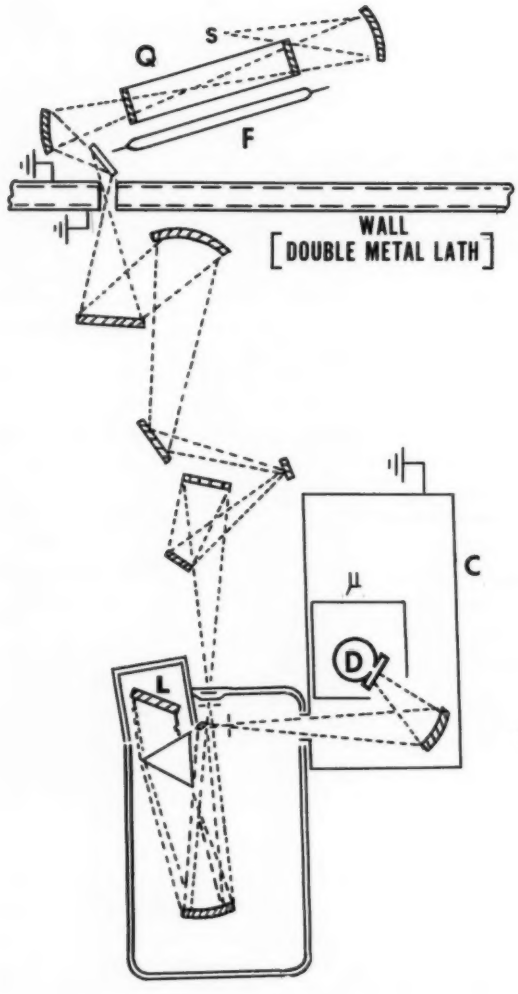


FIG. 1

RAPID-SCAN INFRARED SPECTROPHOTOMETER

netic shielding, copper-screen electrical shielding, and reaction chamber, respectively.

This instrument has successfully demonstrated its applicability to rapid-scan infrared spectroscopy in studies of transient phenomena. Both the identification of short-lived chemical intermediates, produced photolytically, and the kinetic study of systems reacting on a microsecond time scale have been studied. Preliminary emission spectra give promise of chemiluminescence scans prior to equilibration of vibrational degrees of freedom. A variety of other possibilities suggest themselves, such as the investigation of transient species produced by the fast mixing of reactants, by shock waves, and by flash heating techniques. Currently, important problems of inter- and intramolecular energy transfer can also be attacked by this new technique.

The most spectacular effort to which the rapid-scanning infrared spectrophotometer has been applied is the discovery of the chemical lasers already discussed. The use of this tool in surveying chemical reactions for their laser potentialities depends upon the fact that a scan of the reaction shows a suddenly developing peak under certain conditions where coherent light emission occurs. After stimulated emission is indicated, the reaction can be made to take place in a suitable laser cavity, and true coherent laser emission obtained.

The advantage of an efficient chemical laser to the Air Force is obvious. It frees the air- or space-borne vehicle from the tremendous weight penalty necessary to utilize ordinary flash-activated lasers. Electrical-flash-operated lasers need ponderous banks of condensers and heavy electrical generating systems necessary to supply the flash energy. Now that the chemical laser is a reality, it remains only for further applied research to find either more powerful laser-producing reactions, or to discover a chemical reaction which can give multiple flashes for other practical applications of Air Force interest. ★

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